Use of a Radial Turbine in a Thrust Augmentation Scheme

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Theme

A thrust augmentation scheme, for use in launching jet aircraft is analyzed. The proposal utilizes aircraft exhaust kinetic energy to drive a radial turbine.

Contents

The system proposed[1] is portrayed in Fig. 1. It utilizes a partial admission, radial inflow impulse turbine placed in the exhaust of a jet engine. The torque developed by the turbine is used to wrap up, on a capstan, a cable, which may be fixed at some distant point down the runway. The turbine-capstan is mounted on a wheeled platform so that it tends to follow the jet down the runway. A rigid member connects the platform to the turbojet, allegedly exerting an additional thrust.

The equation of motion of the system may be analyzed with the aid of Fig. 2. For the augmenter, we have

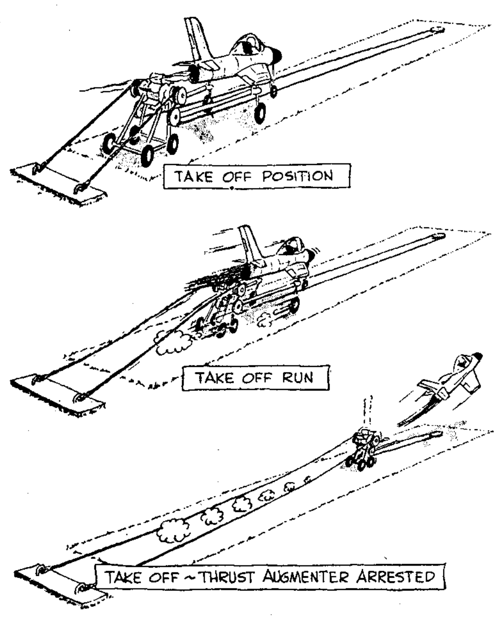

Fig. 1 Thrust augmenter—sequence of operation.

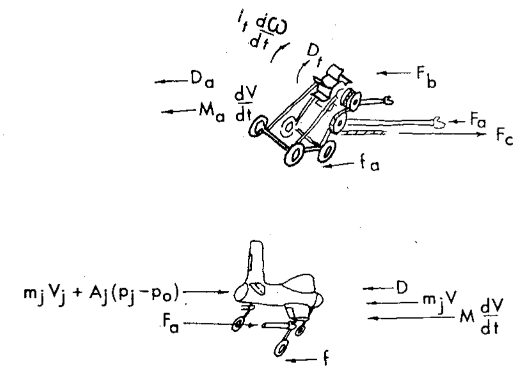

Fig. 2 Forces acting on augmenter and on aircraft.

$$M_a(dV/dt) = F_c - F_a - F_{bx} - D_a - f_a \tag{1}$$

where M, V, F, D, f are respectively; mass, velocity, force, drag, friction force. Subscripts a, c, b are respectively; augmenter, cable, and blade. Note that F_b is the vector blade force, and F_{bx} is its component in the horizontal (x) direction. For the aircraft, we have

$$M\, dV/dt = F_a + m_j V_j + A_j(p_j - p_0) - m_j V - D - f \tag{2}$$

Here m_j, A, and p are respectively; mass flow, area, and pressure. Subscript j refers to the jet. In Eq. (2), we may identify the engine net thrust

$$F_n = m_j V_j + A_j(p_j - p_0) - m_j V \tag{3}$$

Adding Eq. (1) and (2) gives

$$(M + M_a)(dV/dt) = F_n - (D + D_a) - (f + f_a) + (F_c - F_{bx}) \tag{4}$$

Again referring to Fig. 2, angular momentum considerations yield

$$I_t(d\omega/dt) = (F_{b\theta} - D_t)R_t - F_c R_d \tag{5}$$

I_t is the turbine moment of inertia, R is radius, R_d is the drive (capstan) radius, θ refers to tangential component. Eq. (5) may be solved for F_c, and the result used in Eq. (4). Additionally, we introduce x, the distance the system travels. Then

$$V = (dx/dt),\ \omega R_d = \dot{x} \quad \text{and}\ \dot{\omega} R_d = \ddot{x}$$

Writing the drag and friction force in terms of coefficients $D = \frac{1}{2}\rho\dot{x}^2 A C_D$, $D_a = \frac{1}{2}\rho\dot{x}^2 A_a C_{Da}$, $f = \mu M$, $f_a = \mu M_a$. Eq. 4 may now be expressed as

$$\left(M + M_a + \frac{I_t}{R_d^2}\right)\ddot{x} = m_j V_j + A_j(p_j - p_0) - m_j\dot{x} - \tfrac{1}{2}\rho\dot{x}^2(AC_D + A_a C_{Da}) - \mu(M + M_a) + (F_{b\theta} - D_t) \times \frac{R_t}{R_d} - F_{bx} \tag{6}$$

Received February 24, 1972; synoptic received July 27, 1972; revision received September 5, 1972. Full paper available from National Technical Information Service, Springfield, Va., 22151, as N 72-29810 at the standard price (available upon request).

This work was supported by the Naval Air System Command, Contract N0019-69-C-0668.

Index category: Aircraft Performance.

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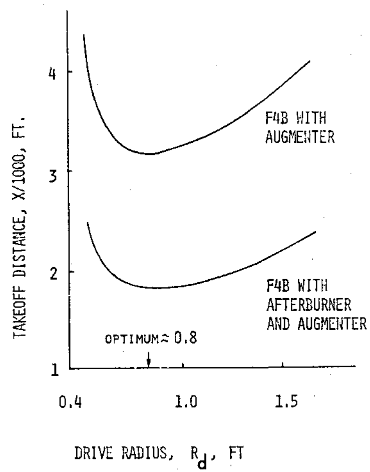

Fig. 3 F-4B takeoff distance as a function of capstan radius.

$F_{b\theta}$, F_{bx}, and D_t may be determined as a function of ω (and hence $\dot{x}$) by simply testing a turbine (with attached dynamometer) or (approximately) by analysis. This second-order equation may then be solved numerically, i.e., by Euler's method.

Tests were conducted on a variety of turbines, always seeking those having large values of $(F_{b\theta} - D_t)/F_{bx}$. An analysis was also performed.

If the (scaled) characteristics of the best turbine tested, data for the F-4B aircraft, a choice for R_t/R_d, and assumptions for the other parameters are introduced into Eq. (6), we may compute $x(t), \dot{x}(t), \ddot{x}(t)$. It turns out that there is an optimum drive radius, that is, a radius which yields the minimum takeoff distance for an assigned takeoff velocity as shown in Fig. 3. It can be seen that decreasing the drive radius will increase the ratio R_t/R_d and hence the blade load term in Eq. (6). However, this increase in R_t/R_d also results in an increase in the maximum speed of the turbine and hence a greater drag.

Table 1 Acceleration characteristics, $R_d = 0.8$ ft

	With augmenter		Without augmenter	
	Max. A/B	Non-A/B	Max. A/B	Non-A/B
Vel. fps	Ground distance, x ft			
100	150	210	270	440
200	610	1100	1210	2150
300	1850	3150	3300	6700
	Acceleration force, $M\ddot{x}$, lbs			
100	58,500	37,300	31,700	18,600
200	47,000	28,800	26,000	14,000
300	31,500	16,200	20,000	7900

Table 1 illustrates how ground accelerations of the F-4B would improve by application of this augmentation scheme. For a takeoff velocity of, say, 300 fps the ground roll is reduced to about half of the normal distance without augmentation.

Reference

[1] *Thrust Augmenter Means*, U.S. Patent Office, Patent 3,400,903 Sept. 10, 1968, assigned to R. B. Cotton, Media, Pa.